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DSTO

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ABSTRACT

This report describes the findings of an investigation into the health of the lubricating oil in two Australian Army CH-47D helicopters. One of the aims of this investigation was to assess the applicability of an existing filter patch test kit for lubricating oil in order to provide basic contamination and wear debris information. The information provided by the filter patch test kit would be of particular benefit when aircraft are deployed to remote localities. The filter patch test kit used for this investigation is currently used by the Australian Defence Force to assess hydraulic fluid health. Another aim of this investigation was to assess a number of chemical and physical properties of the oils in order to obtain a better understanding of the condition of the oils in operational CH-47D helicopters. This investigation also examined whether certain aspects of the oil's chemical condition could be used to assess the health of the aircraft engines and transmissions.

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Executive Summary

This report contains a detailed description of an investigation carried out by the Defence Science and Technology Organisation (DSTO) into the health of lubricating oils in two Australian Army CH-47D helicopters. The first objective of this investigation was to assess the applicability of an existing filter patch test kit to lubricating oils. Lubricating oils from the various engines and transmissions in this aircraft are routinely sampled for Spectrometric Oil Analysis, however, this technique cannot detect particles greater than 5 microns. An advantage of the filter patch technique is that both visible debris and fine debris down to 5 microns are either observed directly or indicated by the shade and colour of the patch. Whilst the engines and transmissions have filtration to varying degrees, debris or contaminants in particular size ranges can continue to circulate possibly leading to damage of load-bearing surfaces.

In general, the presence of contaminants in lubricating oil is considered to be detrimental to rotating components such as bearings, gears, splines and seals. Early detection of gross contamination not removed by filtration can contribute to maximizing the life of these rotating components. Similarly, the early detection of unacceptable wear metal from a transmission or engine can avoid catastrophic failure of the component. It should be emphasized that the purpose of this aspect of the investigation was simply to detect unusual debris; precise quantification or identification was not the aim.

The results of this investigation have shown that this technique can provide basic information about contamination and wear debris particulate in lubricating oils. This information can be obtained in the field and would be of particular benefit to aircraft deployed to remote locations. Whilst the extant Spectrometric Oil Analysis Program provides a valuable elemental analysis of fine wear and contaminant debris, it relies on laboratory analysis that usually involves an unacceptable delay in obtaining results. The application of the proposed technique to the CH-47D aircraft would not require any equipment change, however a minor procedural modification would be required to prevent cross-contamination of fluids.

The second objective of this investigation was to assess the physical and chemical properties of the lubricating oils. The data obtained from these tests provided information about how well the lubricant was performing in service and, by assessing the oil's condition, determined if information about the health of the lubricated system could be obtained. The oil properties investigated were Total Acid Number (TAN), antioxidant and load carrying additive concentration, viscosity and water content.

The oils in the engines and transmissions from both aircraft were found to be in a serviceable condition from a chemical and physical properties perspective. The investigation determined that in some cases the oil's condition was maintained through the large volume of top-up oil added to that system. It was also determined that the CH-47D helicopters did not degrade the chemical and physical properties of the lubricating oil and no significant deviations or trends in the oil's chemical condition were observed.

Authors

Andrew Becker
Air Vehicles Division

Mr Becker joined the Royal Australian Navy (RAN) in 1986 as a helicopter technician working on Sea King helicopters. He was selected for RAN-sponsored degree studies in 1989 and graduated from RMIT in 1993 with a Bachelor of Mechanical Engineering degree with first class honours. Mr Becker then served as an Officer in the Marine Engineering branch of the RAN, during which time he served primarily in the guided missile destroyer HMAS Brisbane. He was then selected for an exchange posting to the United Kingdom where he worked at the training establishment HMS Sultan. Mr Becker resigned his RAN commission in 1998 and joined DSTO. Since then he has worked in the Machine Dynamics area focusing on applied condition monitoring of aircraft propulsion systems and active vibration control prototype systems. Mr Becker has recently completed a Masters Degree in Maintenance and Reliability Engineering.

Paul Rawson
Air Vehicles Division

Paul Rawson graduated with a Degree in Applied Science from University of South Australia in 1986. He worked at Mobil Port Stanvac oil refinery for two years before joining DSTO in the Propellants group at DSTO Salisbury. He joined the AED Fuel & Lubrication Systems facility in 1991, from WSD Salisbury, where he was involved in research into formulation of composite rocket propellants. The duties in his current position as a Senior Officer have mainly involved research into aviation fuel thermal and storage stability, and oil condition monitoring in ADF aircraft.

Contents

1. Introduction

This report details the results of an investigation conducted by DSTO on the engine and gearbox lubricating oil condition of two Australian Army CH-47D helicopters. DSTO approached the Army Aviation Systems Project Office (AASPO) and proposed a program to analyse oil samples from two of the six aircraft in the CH-47D fleet. The work was endorsed by AASPO and included as a component of tasks AIR 01/160 and AIR 01/391. The two aircraft selected for the program were chosen because they had vastly different operating hours; one was relatively new and the other had been in operation since 1995. The purpose of this program was to increase the understanding of the oil condition in operational aircraft and make recommendations on how oil cleanliness and oil chemical condition could be improved or used to monitor the health of the internal components. Oil samples were taken at 25 airframe-hour intervals from each of the five transmissions and two engines per aircraft; these samples were then sent to DSTO for analysis. The sampling period aligned with the sampling period for the Spectrometric Oil Analysis (SOA) program conducted on all aircraft in this fleet. SOA can resolve elemental concentration for oil-entrained particulate up to a maximum of approximately 5 microns [1]. The analysis conducted by DSTO focused on aspects of oil condition that may not be detected or analysed in the SOA program, such as larger particulate contamination and oil chemical condition. It is important to note that the extant SOA program only provides information about water content and viscosity (in addition to the wear-metal elemental analysis).

The oil in helicopter engines and transmissions provides lubrication of moving parts, removes heat and reduces friction. To provide optimum service and ensure maximum component life, the oil must be both free of particulate contamination and retain its bulk chemical and additive condition. In this context, particulate contamination can be either wear-related debris from machine elements such as gears or bearings (e.g. cutting, fatigue or sliding debris), residual build debris (e.g. grit blast residue or machining swarf) or foreign material encountered during operation or servicing (e.g. dirt or sand). The chemical condition of the oil refers to the levels of additive remaining in the oil (e.g. phosphorus as a wear additive), the absence of water from the oil and other physical properties (e.g. viscosity). The lubrication film for aircraft machinery is in the order of 0.1 to 1 microns thick [2] and a typical helicopter main rotor transmission filter would have a filter rating of 30 micron (nominal). It can be seen that the typical filtration system will not necessarily remove all particles that have the potential to interfere with the lubrication film and cause subsequent damage to internal machine elements. Whilst viscosity is measured regularly for Australian Defence Force (ADF) aircraft, other chemical parameters generally are not.

Oil samples were taken from aircraft A15-102 and A15-202, commencing in July 2001 and concluding in October 2002. During this period a total of 15 sets of oil samples were received and analysed by DSTO, each set consisting of one sample from each of the two engines and five gearboxes per aircraft. A15-102 is one of the original four CH-47D

helicopters that the Australian Army took delivery of in 1995. A15-202 is one of two CH-47D helicopters added to the fleet in 2001.

1.1 System Description

The CH-47D transmission system consists of two Honeywell T55-L-712 gas turbines and five transmissions of varying complexity. Figure 1 shows the main features of the CH-47D transmission system [3]. The Engine Transmission is a relatively simple, single-reduction, bevel gearbox incorporating a sprag clutch, whilst the Combining Transmission consists of a dual input, single-reduction, helical-bevel gear stage. Both the Forward and Aft Transmissions have a single bevel stage combined with two epicyclic stages prior to the final rotor output.

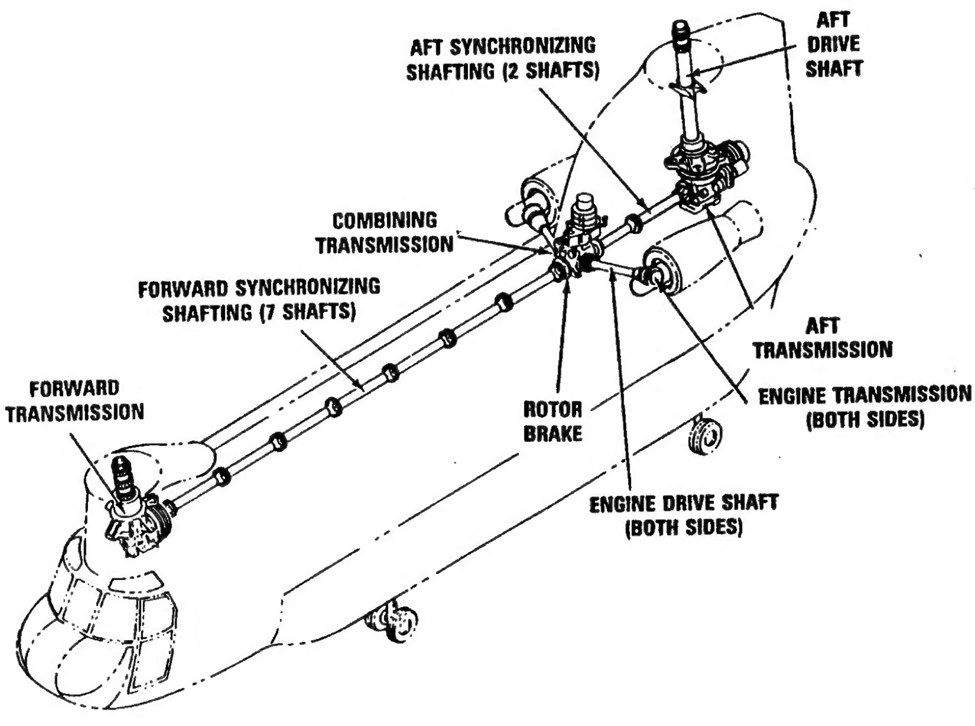

Figure 1: CH-47D aircraft transmission system

1.1.1 Lubrication Systems

Each engine has a self-contained lubrication system consisting of a pressure supply system and a scavenge system. The system contains a disposable 5 micron (nominal) filter element and three magnetic chip detectors that indicate on the maintenance panel inside the aircraft should debris of sufficient size be detected. A blocked filter resulting in a pressure differential across the filter of between 14 to 16 psi (97 to 110 kPa) will cause the filter to be

bypassed and preserve lubrication to the engine components. A visual bypass indicator on the filter activates when the pressure differential exceeds 9 to 12 psi (62 to 83 kPa).

The reservoirs for the Engine Transmissions and the Combining Transmission are contained in a common segmented housing located on the Combining Transmission, with each system containing a disposable 30 micron (nominal) filter. Supply and scavenge pipes connect the Engine Transmissions to the respective reservoirs. Each Engine Transmission has a dedicated lubricating system consisting of a pressure supply system and a scavenge system. Indicating screens are fitted to each engine transmission system that activate when sufficient metallic debris forms a contact between the two screen elements. A blocked filter resulting in a pressure differential across the filter of between 25 to 30 psi (172 to 207 kPa) will cause the filter to be bypassed and preserve lubrication to the transmission components. A visual bypass indicator on the filter activates when the pressure differential is between 15 to 18 psi (103 to 124 kPa).

The Combining Transmission has a magnetic chip detector (that indicates on the maintenance panel) fitted to the sump in addition to debris screens (that also indicate on the maintenance panel) similar to those fitted to the Engine Transmissions. The Combining Transmission filter is a larger version of the filter fitted to the Engine Transmissions, and bypasses at the same differential pressure.

The Forward and Aft Transmissions both contain a disposable 30 micron (nominal) filter as the primary filter as well as an auxiliary 80 micron (nominal) filter. A blocked filter resulting in a pressure differential across the filter of between 25 to 30 psi (172 to 207 kPa) will cause the filter to be bypassed and preserve lubrication to the transmission components. A visual bypass indicator on the filter activates when the pressure differential is between 15 to 18 psi (103 to 124 kPa). A combined debris screen and indicating magnetic chip detector is fitted to each Forward and Aft Transmission.

2. Oil Particulate Analysis

2.1 Filter Patch Method

This aspect of the oil analysis investigation focused on the analysis of entrained particulate using the Millipore colour patch test kit [4]. This method involves passing 100 ml of sample through a 5 micron filter membrane (patch) and then assessing both the colour of the patch and the extent of visible particulate. Assessment is carried out by comparing the filter patch to a series of reference standard cards. This technique was designed to assess contamination levels in aircraft hydraulic fluids, however, it can also be used to assess lubricating oils [5]. The prime advantage of this method is that all debris larger than 5 microns is captured for assessment regardless of composition. For example ferrous metal, non-ferrous metal, organic solids and inorganic solids (including fibres) are all captured for assessment.

Another advantage of using this method is that the equipment is currently used in the ADF for periodic hydraulic fluid assessment and could therefore be readily applied to lubricating oils. The main issue that was unclear when applying this technique to lubricating oils was whether the reference standard provided with the kit was applicable given that the technique was developed for hydraulic fluids and systems with generally finer filtration. Despite the fact that this method of assessment is semi-quantitative (i.e. there is some judgement involved), it was thought that it would provide an adequate measure of lubricant contamination for in-field applications where laboratory techniques were not readily available (such as deployments to ships or remote localities). A common criticism of the SOA technique is that the results of the analysis are rarely conveyed back to the maintenance staff in a timely manner, whereas the proposed technique would provide some instant feedback, albeit of a limited nature.

2.1.1 Standards

There are a number of standards that can be used to assess the cleanliness of an oil, however the function of the oil needs to be taken into consideration when applying a particular standard. One method for coding the extent of particle contamination of hydraulic systems is covered by AS 4002.1-2001 [6]. This standard is identical to the internationally accepted ISO 4406:1999 standard and uses either a two or three number code (depending on the method of particle counting) to describe the extent of particulate contamination in hydraulic systems. This standard uses 30 code numbers to represent the number of particles per millilitre of hydraulic fluid. For microscopic particle counting a two number code is used [7]; the first number relates to the number of particles greater than or equal to 5 micron per millilitre of fluid, whilst the second number relates to the number of particles greater than or equal to 15 microns per millilitre of fluid. For example, the Class 5 contamination shown in table 1 translates approximately to an ISO cleanliness code of 17/15. For other particle counting methods an additional code number is included to indicate the quantity of particles above 2 microns. This standard is of limited use for this application as it is specifically intended as a hydraulic fluid standard and therefore is not necessarily applicable to lubricants in aircraft transmissions and engines.

Another contamination standard applicable specifically to military aircraft is the United States Navy Standard for Particulate Contamination (Table 1) [8]. This standard is applicable to both particle counting (microscopic or automatic) and the filter patch method since the three reference standards supplied with the filter patch kit refer directly to Class 1,3 and 5 of the U.S. Navy standard (see Table 1). The colour patch component of this standard is ideal for contamination assessment in the field, as gross visible particulates are readily observed and the colour rating obtained is directly related to a contamination class that is based on particle counts. It should be noted that the particle counts shown in Table 1 are based on a 100 ml sample whereas the ISO codes relate to the number of particles per millilitre. The in-field comparison reference standards in conjunction with the United States Navy Standard for Particulate Contamination were used for this investigation.

Although the United States Navy Standard for Particulate Contamination does show examples of visible particulate contamination, it does not contain any scale associated with the severity of this contamination. Whilst any visible particulate contamination may be considered unacceptable in a hydraulics system, transmission and engine lubrication systems are generally more tolerant of some particulate contamination. It was decided to create a scale to enable the severity of the visible particulate contamination to be assessed. The scale consists of four levels: Trace, Slight, Moderate and Severe. Appendix A.1 contains pictures of filter patches corresponding to the new scale.

Table 1: Extract from NAVAIR 01-1A-17 showing the U.S. Navy Standard for Particulate Contamination

PARTICLE CONTAMINATION LEVEL-BY CLASS *Acceptable*							*Unacceptable*
Class	*0*	***1***	*2*	***3***	*4*	***5***	*6*
5-10μm range	2,700	**4,600**	9,700	**24,000**	32,000	**87,000**	128,000
10-25μm	670	**1,340**	2,680	**5,360**	10,700	**21,400**	42,000
25-50μm	93	**210**	380	**780**	1,510	**3,130**	6,500
50-100μm	16	**28**	56	**110**	225	**430**	1,000
Over 100μm	1	**3**	5	**11**	21	**41**	92

Note: The particle counts shown in this table are based on the particle count per 100 ml of fluid. ISO codes are based on the particle count per millilitre.

2.2 Results

Lubricating oil samples from A15-102 and A15-202 were processed and examined in accordance with NAVAIR 01-1A-17 [9]. A total of 105 samples were obtained; 42 from A15-102 and 63 from A15-202. Comparative assessments were made of the test filters obtained against the Naval Aviation Hydraulic Fluid Contamination Standards (reference cards used for in-field assessment). The results of this analysis appear in Appendix A.

2.2.1 Particulate Analysis Results

The NAVAIR colour rating for each sample revealed only three instances of unacceptable contamination out of the 105 samples analysed. This aspect of the patch assessment refers only to the overall colour of the patch (which relates to the presence of particles up to approximately 40 micron) and does not provide any indication about the presence of visible particulate (which relates to particles approximately 40 micron and larger). Figure 2 is a histogram of the results obtained for the entire set of samples and shows that the majority of samples returned a NAVAIR rating of 3, which can be considered a good result for a lubrication system. All of the NAVAIR 6 (Unacceptable) samples came from different types of components fitted to aircraft A15-202 (No. 2 Engine, No. 1 Engine Transmission and the Forward Transmission). This may indicate wear-in of components given the relatively low operational hours of the major assemblies of this aircraft.

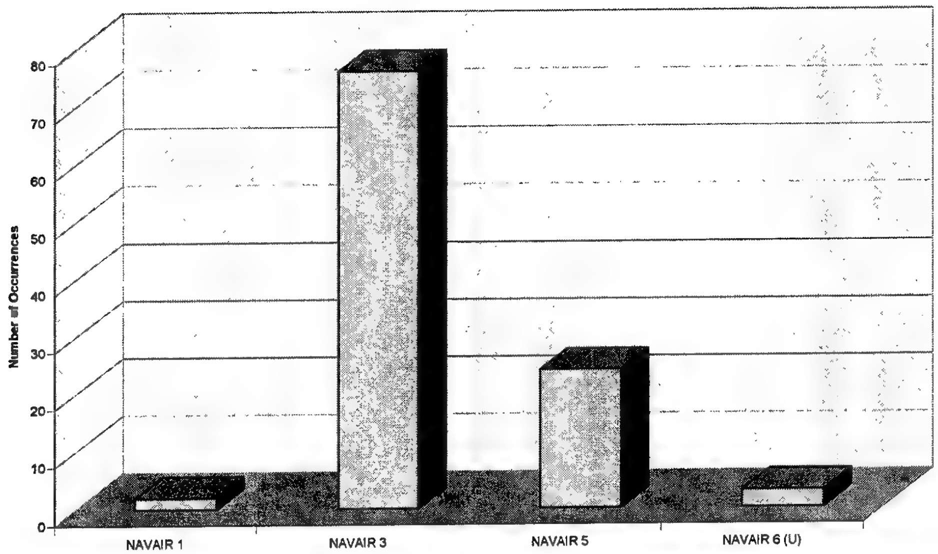

Figure 2: Histogram of NAVAIR Colour Rating

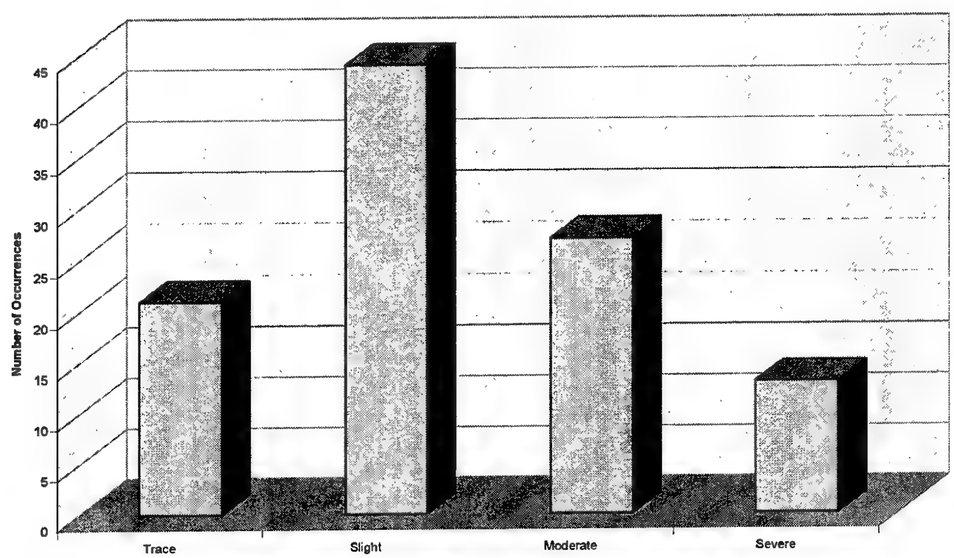

Figure 3: Histogram of Visible Particulate Contamination

The visible contamination assessment was conducted using the newly created scale (see Appendix A.1). Thirteen instances of severe visible contamination were identified, one of which was contaminated to the extent that an immediate oil flush was ordered for that system [10]. Figure 3 shows a histogram of the visible particulate results and shows that the majority of samples contained Slight or Trace levels of visible contamination. Figure 4

shows the distribution of the samples graded as Severe and shows that the majority of instances were recorded from samples taken from the Combining Transmission and Engine Transmissions (as previously stated there is a common segmented housing for the reservoirs of these transmissions).

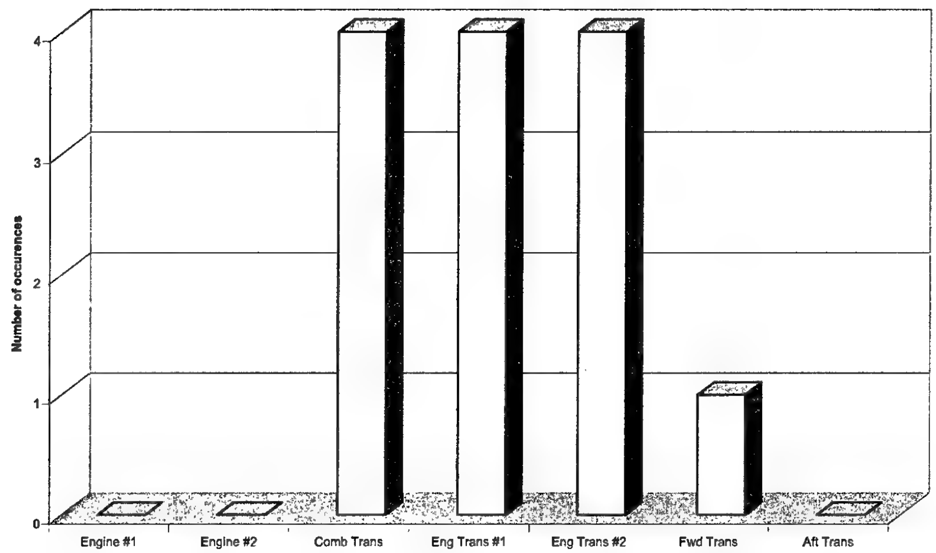

Figure 4: Distribution of Severe Visual Contamination

Figure 5 shows the distribution of the Severe visual contamination by aircraft tail number. Interestingly, the newer aircraft (A15-202) shows more instances of severe visible contamination than the fleet leader (A15-102). As can be seen in Table 2, most major assemblies fitted to A15-102 had operating hours in the range 900 to 3000 hours

Table 2: Major Assembly Operating Hours at Commencement of Sampling Period

Component	*A15-102*	*A15-202*
No. 1 Engine	1735.1	221.7
No. 2 Engine	2739.2	221.7
No. 1 Engine Transmission	**121.9**	221.7
No. 2 Engine Transmission	906.7	221.7
Combining Transmission	1321.2	221.7
Forward Transmission	1270.1	221.7
Aft Transmission	1270.1	221.7

(with the exception of No. 1 Engine Transmission). The No. 1 Engine Transmission had been replaced and only had 121.9 operating hours at the commencement of the sampling period. Interestingly it was this transmission that returned three of the 4 Severe particulate

results. At the commencement of this trial all major assemblies fitted to A15-202 had 221.7 operating hours.

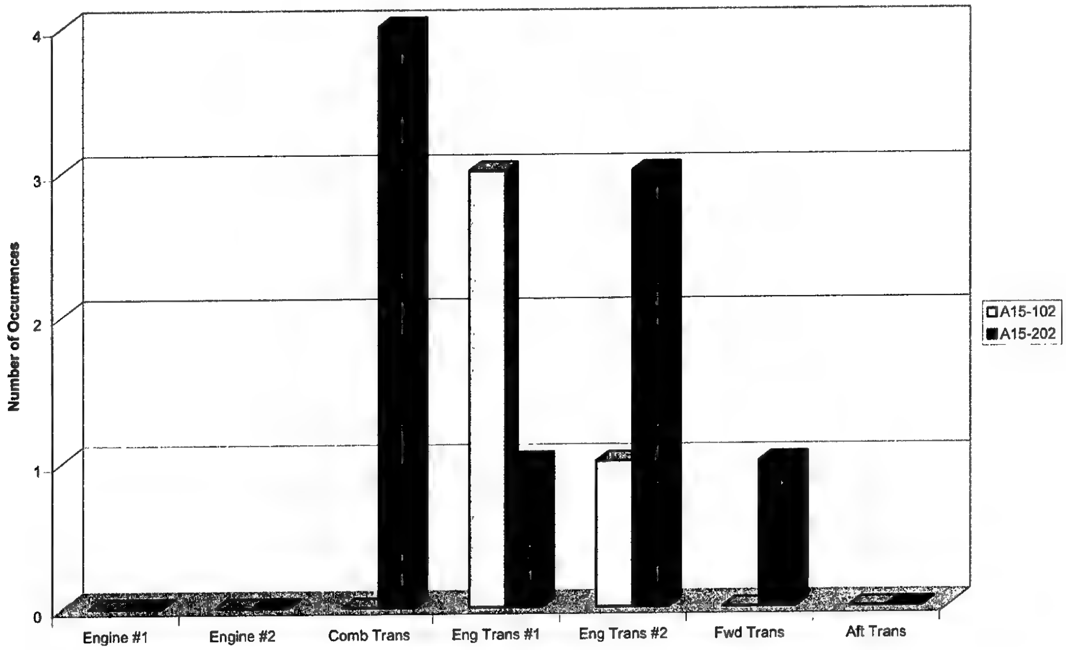

Figure 5: Comparison of Gross Visible Contamination by Aircraft Tail Number

The majority of the visible particulate contamination was later confirmed to be silicon based grit up to approximately 600 micron (see section 2.2.2). The amount of visible wear-metal in all samples from both aircraft was extremely low with only occasional pieces being observed on the patches. Identification of wear metal was relatively easy using this method and low magnification (x40). Figure 6 shows an example of wear- metal that was detected on the filter patches.

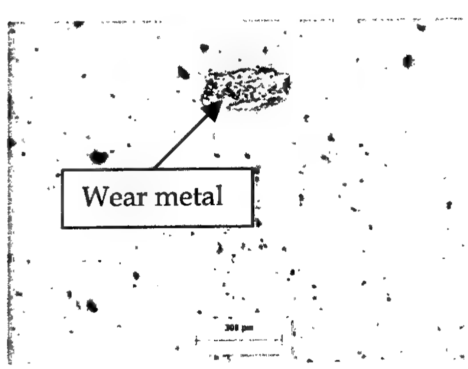

Figure 6: Examples of visible wear metal

Whilst the purpose of this investigation was not to perform a detailed examination of the wear-metal, its discovery shows that detection of visible wear metal (100 micron and larger) could be readily accomplished in the field. Wear metal found using this technique could then be sent to a laboratory for further investigation.

2.2.2 SEM Analysis of Particulate

Samples of the Severe visible contamination were analysed using a Scanning Electron Microscope (SEM) in order to ascertain the origin of the particulate. Analysis of the particulate revealed that the majority of the visible contamination was silicon-based grit up to 200 micron [11], however particles up to 600 micron were observed on some patches. Initially, it was thought that the contamination could have been manufacturing residue from grit blasting procedures, however corundum (Al_2O_3) is the standard grit used for aeronautical applications. Figure 7 shows an example of the severe visible contamination observed.

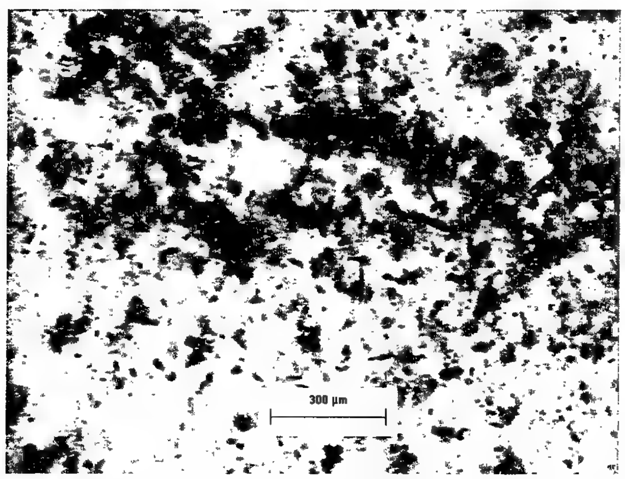

Figure 7: Example of Severe Visible Contamination from Aircraft A15-202

Figure 8 shows a typical SEM image of the severe visible contamination found during this investigation. Figure 9 shows the Energy Dispersive Spectroscopy (EDS) spectrum from a typical contaminant and shows the dominant silicon peak.

Figure 8: SEM image of typical debris

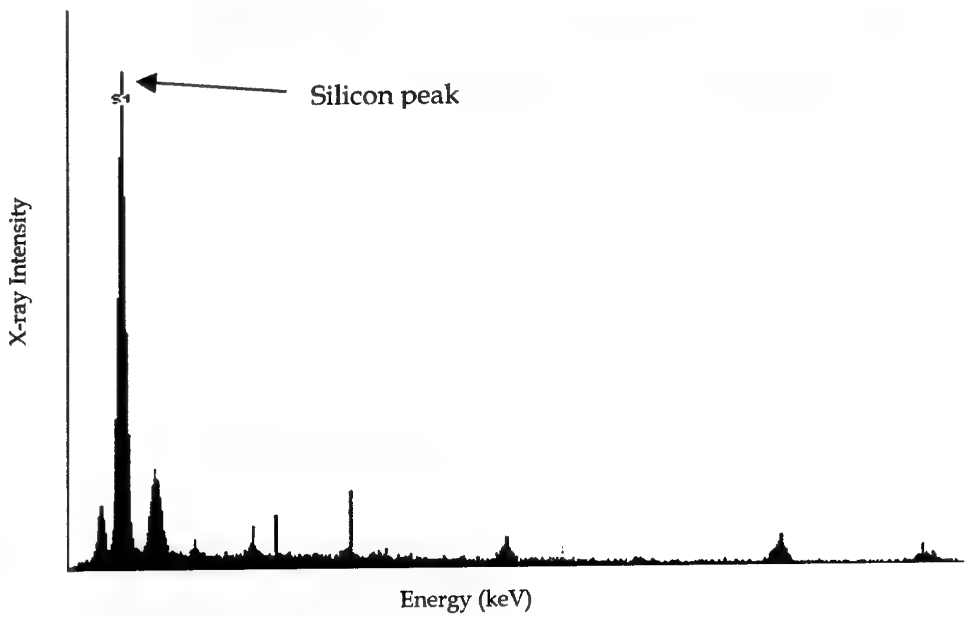

Figure 9: SEM EDS spectum of typical debris showing significant silicon content

3. Oil Chemistry Analysis

Condition monitoring of aircraft lubricant systems is well established with respect to wear metal analysis. However, an area that is often neglected is the condition of the oil's chemical and physical properties. Oil that has its base lubricant or additive package chemically or mechanically degraded may no longer provide adequate lubrication and may be degraded to such a state that it will damage oil-wetted system components, either through corrosion or inability to provide effective load carrying capacity under elastohydrodynamic lubrication conditions.

Most modern helicopter engines and transmissions are lubricated with synthetic oil. These oils are designed specifically to meet the requirements of high temperature gas turbines and high speed transmission operations over the range of flight environment temperatures. The CH-47D aircraft investigated in this study use O-156 (MIL-L-23699) specification oil, which is synthetic polyolester-based oil. This oil contains an additive package to ensure serviceable operation over the expected operating conditions and system demands placed upon the oil.

Oils are normally formulated to comply with specifications, and as such their formulations can vary from batch to batch. The exact composition of the oil is not normally given by the manufacturers. The O-156 specification oil contains a number of additives that ensure its optimal performance over the entire range of operating requirements.

The O-156 oil contains the load carrying additive tricresyl phosphate (TCP), which is known to reduce both friction and wear. Load carrying additives, or antiwear additives as they are commonly known, are added to the oil to reduce wear in system operating conditions when metal surface asperities begin to interact. The TCP is added to the oil at approximately 2.8 - 3% by weight. Phosphorus-containing additives, such as TCP, are used to provide protection against moderate to high pressure metal-to-metal contact. It is useful to monitor the TCP concentration because an oil subject to wear or metal-to-metal contact in a lubricated system will lose the TCP as the additive leaves the bulk oil and adheres to the freshly worn metal surface. In some cases, it is possible to determine if a system is undergoing abnormal wear by monitoring the depletion of TCP with time. Abnormal depletion of the TCP can indicate the onset of metal to metal interactions and, when used in association with increases in metal as determined by a SOA program, the system maintainer can more confidently predict system wear and the onset of possible failures.

The oil has an antioxidant package which, in the O-156 examined, contains two antioxidants, phenyl alpha naphthylamine (PAN) and dioctyl diphenylamine. Their primary function is to inhibit oxidation reactions in the lubricant base stock. If left unchecked, these oxidation reactions will propagate to form high molecular weight polymeric sludges. The antioxidants are consumed in providing this function. The base level is approximately 0.9-1% by weight for each of the two specific antioxidant compounds used in the O-156 oil examined in this report.

The oil contains a viscosity index improver (VI), which provides the fluid with uniform viscosity over as board range of temperatures. Viscosity improvers are generally inherently chemically stable and undergo reaction by mechanical shearing, reducing the fluid's viscosity with time in service. Mechanical shearing is usually associated with operation in transmissions and not normally associated with gas turbine engine lubrication. It is important to maintain the oil's viscosity within specification limits so the lubricant can be most effective at preventing wear and minimising friction between mating surfaces. The oil's viscosity must be within a specified range to ensure it will form a hydrodynamic film between moving metal parts, but should not be so thick as to induce excessive viscous drag losses. If the viscosity decreases due to shearing of the oil, the lubricant film thickness will decrease, allowing metal-to-metal component contact. If this occurs the lubricated components will begin to wear. If the viscosity is too high, due to thermal oxidation and polymerisation reactions, then it may not flow through fine orifices. For oil that has thickened in service, energy is wasted overcoming the thicker oil's resistance to flow [12]. The loss of power attributed to overcoming the more viscous oil can be significant. For example, in Black Hawk main transmissions an efficiency decrease of 0.5% represents about 100 lb (45.4 kg) of lost payload [13].

The assessment of the oil's chemical and physical property health was aimed at determining the requirements of an Oil Condition Monitoring (OCM) program for engines and transmissions in the CH-47D. The chemical and physical properties examined were those most significant in the assessment of the oil's serviceability.

A lubricating oil is manufactured to meet a wide range of physical, chemical and performance requirements. These requirements are defined by a performance specification that controls the oil's physical and chemical properties to ensure it is suitable for service and meet the basic lubrication requirements of an engine or transmission. The specifications control many oil chemical and physical properties, however, the following oil properties were considered to be the most useful in determining condition as they give a measure of the oil's health and level of degradation. The oil properties monitored were Total Acid Number (TAN), water, viscosity, antioxidant and load carrying additive concentrations. These properties were then trended against time in service to establish if oil in the CH-47D systems remained in serviceable condition over the trial period and if any of the systems acted to degrade the oil to an unserviceable state. This information can then be used to establish strategies for maintaining optimum oil condition and thus system operation.

The water content of the oil is an important property due to O-156 being an ester based oil. The ester base stock may undergo hydrolysis in the presence of water and form organic acids. These acids will corrode metals in the lubricated system, and have been found to be very corrosive of magnesium alloys. The recommended in-service maximum for water in the ester-based oil is 1500 ppm. The oil should be changed or purified if the water concentration reaches this level.

The oil's acidity can be increased by a number of degradation mechanisms, including hydrolysis with water, oxidation and thermal degradation [14], where the oil is heated and oxidises under otherwise normal operation. Thermal oxidative degradation is normally associated with engine oils and causes the base stock to form acidic reaction products, which will increase the oil's total acidity.

3.1 Results

3.1.1 Chemical and Physical Property Analysis

Oil samples from each aircraft's five transmissions and two engines were analysed. The oil's TAN, water content, load carrying additive concentration, antioxidant concentration (PAN) and viscosity were determined at approximately 25 flight hour intervals. This data was then trended to assess the oil's chemical and physical property changes with time in service. During the investigation both aircraft required top-up oil due to normal usage of the oil and leakage. Table 3 gives total top up quantities for both aircraft.

Table 3: Oil Top Up Totals for Each Aircraft System

Component	A15-102 (quarts)	A15-202 (quarts)
No. 1 Engine	7.25	4.25
No. 2 Engine	7.25	14
No. 1 Engine Transmission	0	0
No. 2 Engine Transmission	0	0
Aft Transmission	5	6.5
Combining Transmission	11	49
Forward Transmission	7	3.25

3.1.2 Viscosity

The oil's time in service for A15-102 was not supplied and was not new at the beginning of the trial so its actual time in service was unknown. The O-156 (MIL-L-23699) specification oil used in the CH-47D has a specified minimum viscosity at 40°C of 23 cSt. Batches of the oil normally have fresh viscosities from 24.5 - 25.5 cSt.

None of the CH-47D systems showed significant changes from the initial viscosity after approximately 180 hours for A15-102 (Figure B1.1) and 280 hours for A15-202 (Figure B2.1). There is an increase in the viscosity of all A15-202 transmissions, this is due to these systems initially containing the MIL-L-7808 oil used by United States Air Force, which has a lower base viscosity. The increase in viscosity is due to top ups of the systems with the higher viscosity O-156 oil. The MIL-L-7808 is completely compatible with the O-156 oil so there are no issues of oil compatibility associated with the mixing of these different specification oils. There were no other significant changes in viscosity in any of the

systems examined. The engine oils have not been subjected to significant thermal stress and the viscosity improver in the transmission oils has not degraded through shearing.

3.1.3 Water

The levels of water in all systems in the CH-47Ds have decreased with time in service, especially in the engines (Figures B1.2 and B2.2). The decrease of water in the engine oils is expected as they run hotter than the transmissions and will tend to drive water out of the systems. Water will absorb into the oil when the helicopter is idle for extended periods and will tend to be driven out of the oil under normal operating temperatures.

The issue of static corrosion of helicopter transmissions has been identified by the United States Navy as one of the major failings of the O-156 oil. That is, its inability to thwart the static corrosion of bearings during long periods of engine and transmission inactivity [15]. In some instances static corrosion in helicopter transmission containing magnesium alloy may manifest it self as a purple sludge.

The oil water content for both aircraft has been maintained well below the 1500ppm maximum. A corrosion-inhibited version of the O-156 oil is available which would offer improved resistance to static corrosion if the aircraft was to sit idle for extended periods.

3.1.4 Total Acid Number

Fresh O-156 oil will normally have a TAN in the range 0.05-0.1 mgKOH/g. The TAN of the oils in both aircraft are well under the in-service maximum of 2.0 mgKOH/g recommended in AAP 7210.009-2-16 (Chapter 4. Oil Condition Analysis). The No. 1 Engine for A15-202 (Figure B2.3) and No.2 engine for A15-102 (Figure B1.3) showed an increase in TAN, which is consistent with normal engine operation. The No. 2 Engine of A15-202 TAN was lower than expected but 14 quarts of top up oil had been added to this system. The addition of top-up oil maintained a low TAN in the oil system.

3.1.5 Load Carrying Additive

The TCP concentration for A15-202 was determined only for the engines and not the transmissions since the transmissions initially contained MIL-L-7808 oil (see Section 3.1.2). The ADF does not normally use the MIL-L-7808 oil and its load carrying additive package has not been characterised in detail by DSTO. The ADF uses the higher viscosity MIL-L-23699 in place of MIL-L-7808 and it has been found that some ADF equipment received from the USA has been delivered with the MIL-L-7808 fluid.

There is currently no in-service limit set for the levels of load carrying additives. A proposed limit of 1.8% minimum is being examined by DSTO and is based on the oil manufacturer's experience with commercial engine operation. The minimum requirement for load carrying additive in an oil will be different for engine and transmission operation.

Limits will need to be developed through investigations such as this one and only conservative estimates can be offered until more operational experience is obtained.

None of the systems examined showed a loss of TCP with time in service (Figures B1.4 and B2.4). Some systems showed an increasing trend in TCP concentration, which is due to top-up oil. The method used to determine the TCP concentration was found to have a relatively large standard deviation. An alternate method for determining the TCP concentration of the oil was trialed. This alternate method was based on measuring the phosphorus content of the oil and had a significantly better precision. It is recommended that if the load-carrying additive is to be monitoring routinely then the phosphorus concentration of the oil be monitored under the SOA program, as this will provide a significantly more accurate method for quantifying the TCP levels in the oil.

3.1.6 Antioxidant

The increases in antioxidant (AO) concentration of A15-102 forward transmission correspond with oil top-up (Figure B1.5). The No. 1 Engines for both A15-102 and A15-202 (Figure B2.5) showed a minor decrease in AO with time in service, which is expected for normal engine operations. The No. 2 Engines for both aircraft have essentially unchanged AO levels. The engines in both CH-47D helicopters examined were not degrading the oil due to thermal stress.

A number of the CH-47D engines and transmissions showed increases in AO concentrations rather than a decrease, which is expected with normal system operation. These increases are all attributed to the significant levels of oil top up, in one case as much as 49 quarts (46.4 L). It was apparent that the oil AO level was being maintained by the periodic top-ups. In contrast, the No. 1 Engine Transmission and No. 2 Engine Transmission for A15-102 did not have any addition of top-up oil and no change in the oil AO was apparent. The oil in the aircraft transmission was not expected to undergo degradation due to thermal oxidation, this result confirms this expectation.

The inter-dependence of oil chemical properties can be seen by examining the A15-202 No. 1 Engine AO concentration which depletes with time in service and this engine shows a corresponding increase in TAN, that is acidic by-products of the oxidative degradation of the oil have been formed. These changes in antioxidant and TAN for this engine are small and the oil is well within maximum limits.

4. Discussion

4.1 Oil Particulate Analysis

The filter patch analysis conducted on aircraft A15-102 and A15-202 showed that most lubricating oil samples were free from severe visible contamination and wear debris.

However, severe visible silicon-based grit contamination was identified repeatedly in some lubricating systems. In particular the Combining Transmission and Engine Transmission lubricating systems regularly featured visible contamination. In addition the bulk colour of the patches indicated that, in some cases, unacceptable fine wear debris was present (based on hydraulic system standards). In contrast, the majority of samples analysed from the Forward and Aft Transmissions were free from visible contamination and visible wear debris. The higher level of filtration applied to the engine lubricating systems appeared to limit the visible particulate to Trace or Slight in all cases. The overall patch colour, however, indicated that wear metal was still present in the lubricant in significant quantities and, in one case, the patch was assessed as unacceptable (see Appendix A). The visible contamination results unexpectedly showed that assemblies with relatively low operating hours accounted for the majority of contamination.

In general, the presence of silicon-based visible contamination of the size observed in a number of assemblies is not conducive to maximizing component life. The silicon-based contamination is likely to have come from ingestion through faulty seals or breather caps, however it could also have been introduced by dirty replenishment devices. Consideration should be given to implementing the filter patch assessment for all CH-47D helicopters in conjunction with a method of purifying lubricating oil identified as contaminated. Investigation into the cause of the contamination must also be written into any amended procedures. Finer filtration on the aircraft for selected assemblies may also help to improve the lubricant's health. It should be re-emphasized that the SOA program currently operating on these aircraft would not detect the visible contaminants identified during this investigation due to the size limitation of SOA (less than 5 micron only). The filter patch could be relatively easily implemented on the Australian Army fleet of CH-47Ds, and could be applied to other aircraft and defence assets. Upon detection of a severely contaminated oil system, an investigation into the root cause should be undertaken in addition to flushing the oil system. In short, oil cleanliness is one of the key methods of maximising the life of components in assemblies such as transmissions and engines.

The particulate analysis aspect of this investigation has demonstrated that the filter patch test is able to provide basic oil cleanliness information that would be useful where aircraft are deployed to remote localities or where access to laboratory analysis is either unavailable or not timely enough. Whilst the results are not strictly quantitative, the information provided is easily obtained in the field and can be readily sent to laboratories for further analysis if required. The equipment required for the filter patch test can be used in its current form with no modification and only minor variation to the operating procedure. The main alteration would involve enforcing a rigorous equipment cleaning regime to prevent false readings from cross-contamination between lubricating assemblies and hydraulic systems.

Whilst the filter patch test does not provide completely quantitative results, there is scope for the analytical process to be enhanced by using digital imaging techniques and particle counting software specifically tailored for in-field military use.

4.2 Oil Chemistry Analysis

The chemical and physical properties analysis conducted on the CH-47D helicopters revealed that the oils were in serviceable condition. Some aspects of the analysis were significantly affected by the amount of top-up oil added to the various systems, and the oils did not suffer as great a level of degradation as was initially expected.

The significance of water removal from the aircraft systems has been highlighted by the finding of purple coloured sludges in O-156 Black Hawk helicopter transmissions. The sludge was found to be capable of rapid filter blockage and has also been observed by the USA and UK helicopter community [16]. The sludge is a direct consequence of the ester oil hydrolysing with water and then reacting with the oil's additives and magnesium metal in the lubricated components.

The current ester based synthetic oils used in the CH-47D is a mature oil type in that it has had approximately 40 years of study and continuing improvement of its formulation. As such, few problems are expected with its use in current helicopter engines and transmissions [17]. However, the oil will still deteriorate with time in service due to normal thermal oxidative mechanisms, exposure to water, wear metals and other contaminants. It is desirable to understand the performance of the oils in each helicopter system to ensure that expected oil performance is maintained over the normal component service life.

United States Air Force and United States Navy historical data indicate that the leading cause for rejection of transmission parts at overhaul for the CH-46 was corrosion; overhaul records for the CH-47C show a similar problem with corrosion. This highlights the need to maintain lubricant quality with respect to TAN and water content [18].

The trending of significant changes in the CH-47D has been complicated by the addition of top-up oil to the various systems. This is despite previous experience with oil condition monitoring programs on other ADF platforms, which showed that trends in oil condition are apparent even with the inclusion of top-up oil. The CH-47D helicopters examined in this investigation have maintained good oil condition over the 180 and 280 hours of operation respectively. Extrapolation of the trend data indicates that the oil will remain in a serviceable condition until major scheduled servicing causes complete replacement of the oils.

5. Conclusion

This investigation has assessed the lubricating oil health of two Australian Army CH-47D helicopters. The aircraft chosen for this investigation were selected because the operating hours of the respective engines and transmissions varied significantly; one aircraft was the

first CH-47D delivered and the other aircraft was one of two additional CH-47D helicopters delivered in 2001.

The particulate contamination and wear debris present in the samples was assessed by using an existing hydraulic fluid filter patch test kit. The main advantage of applying this test kit to lubricating oils is that basic information is available in the field. Whilst the proposed technique does not absolutely quantify or identify contaminants or wear debris, it does detect their presence in a quasi-quantitative manner. The filter patch technique is seen as potentially valuable adjunct to the extant Spectrometric Oil Analysis Program. There is the potential for further development of this technique using advanced imaging techniques to provide more detailed information in the field.

The results of the particulate analysis revealed that the combining and engine transmissions repeatedly showed unacceptable visible contamination. This was later revealed to be silicon based grit, probably ingested during operations.

The oil in both the engines and transmissions of both aircraft was in good chemical and physical condition, and had not been significantly degraded with time in service. The transmissions in A15-202 initially contained the USAF MIL-L-7808, which is compatible with the standard ADF O-156 (MIL-L-23699) oil but is not normally used in ADF aircraft. By the end of the sampling period, however, the transmissions had been replenished using O-156 to the point where it was the dominant lubricant.

6. Recommendations

1. AASPO consider applying routine filter patch testing to lubrication systems in all Australian Army CH-47D aircraft.
2. Further development of the filter patch technique be undertaken by DSTO to investigate methods of extracting more information from the patch using digital imaging techniques.
3. Finer filtration be considered for the Combining and Engine Transmissions in the CH-47D helicopter.
4. DSTO and AASPO investigate whether existing external (to the aircraft) oil filtration rigs can be used periodically to remove contaminants. These rigs are periodically used to cleanse the hydraulic oils in the CH-47D helicopter.
5. Phosphorus be added to the SOA program and trended with oil time in service to monitor the lubricated systems health with respect to wear.
6. A scheduled oil condition monitoring program that assesses the chemical and physical condition of the oil in the CH-47D is not required. However, periodic checks of oil chemical condition should be done to ensure the oil's condition is maintained in service.

7. Acknowledgements

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Appendix A: Particle Analysis Data

Aircraft: **A15-102**			
Sample date: **29 October 2001**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	3	Slight	Grey
No. 2 Engine	1	Slight	Grey
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	Moderate	Grey
No. 2 Engine Trans.	3	Moderate	Grey
Fwd. Trans.	3	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-102**			
Sample date: **14 May 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Slight	Tan
No. 2 Engine	3	Trace	Grey
Comb. Trans.	3	Slight	Grey
No. 1 Engine Trans.	3	Moderate	Grey
No. 2 Engine Trans.	3	Slight	Grey
Fwd. Trans.	5	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-102**			
Sample date: **13 June 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Slight	Tan
No. 2 Engine	3	Slight	Grey
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	Moderate	Grey
No. 2 Engine Trans.	3	Slight	Grey
Fwd. Trans.	3	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-102**			
Sample date: **9 July 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Slight	Tan
No. 2 Engine	3	Slight	Grey
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	**Severe**	Grey
No. 2 Engine Trans.	3	Moderate	Grey
Fwd. Trans.	3	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-102**			
Sample date: **1 August 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	3	Slight	Grey
No. 2 Engine	3	Slight	Grey
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	**Severe**	Grey
No. 2 Engine Trans.	3	**Severe**	Grey
Fwd. Trans.	3	Slight	Grey
Aft Trans	1	Slight	Grey

Aircraft: **A15-102**			
Sample date: **20 September 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	3	Slight	Tan
No. 2 Engine	3	Trace	Grey
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	**Severe**	Grey
No. 2 Engine Trans.	3	Moderate	Grey
Fwd. Trans.	3	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-202**			
Sample date: **29 August 2001**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Trace	Tan
No. 2 Engine	5	Trace	Tan
Comb. Trans.	5	Moderate	Grey
No. 1 Engine Trans.	5	Moderate	Grey
No. 2 Engine Trans.	**6 (Unacceptable)**	**Severe**	Grey
Fwd. Trans.	5	Moderate	Grey
Aft Trans	3	Moderate	Grey

Aircraft: **A15-202**			
Sample date: **17 September 2001**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Trace	Tan
No. 2 Engine	5	Slight	Tan
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	5	Moderate	Grey
No. 2 Engine Trans.	3	Moderate	Grey
Fwd. Trans.	**6 (Unacceptable)**	Moderate	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-202**			
Sample date: **21 November 2001**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Slight	Tan
No. 2 Engine	3	Slight	Tan
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	Moderate	Grey
No. 2 Engine Trans.	3	Moderate	Grey
Fwd. Trans.	3	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-202**			
Sample date: **2 March 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Slight	Tan
No. 2 Engine	5	Trace	Tan
Comb. Trans.	3	Moderate	Grey
No. 1 Engine Trans.	3	Moderate	Grey
No. 2 Engine Trans.	3	Moderate	Grey
Fwd. Trans.	5	Slight	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-202**			
Sample date: **14 May 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	3	Trace	Tan
No. 2 Engine	3	Trace	Tan
Comb. Trans.	5	**Severe**	Grey
No. 1 Engine Trans.	3	Slight	Grey
No. 2 Engine Trans.	3	Slight	Grey
Fwd. Trans.	5	Slight	Grey
Aft Trans	3	Slight	Grey

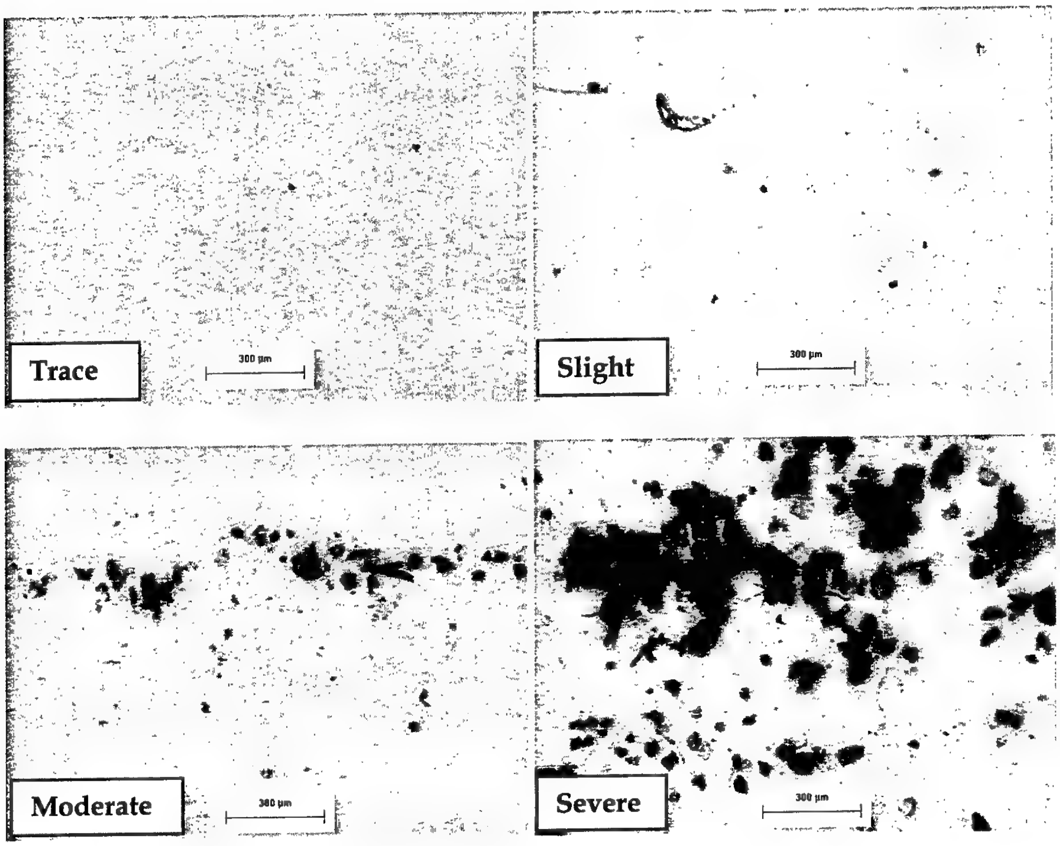
Aircraft: **A15-202**			
Sample date: **24 July 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Trace	Tan
No. 2 Engine	3	Trace	Grey
Comb. Trans.	3	**Severe**	Grey
No. 1 Engine Trans.	3	**Severe**	Grey
No. 2 Engine Trans.	3	**Severe**	Grey
Fwd. Trans.	3	**Severe**	Grey
Aft Trans	3	Slight	Grey

Aircraft: **A15-202**			
Sample date: **11 August 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Trace	Tan
No. 2 Engine	3	Trace	Grey
Comb. Trans.	3	Slight	Grey
No. 1 Engine Trans.	3	Slight	Grey
No. 2 Engine Trans.	3	Slight	Grey
Fwd. Trans.	5	Slight	Grey
Aft Trans	3	Trace	Grey

Aircraft: **A15-202**			
Sample date: **26 August 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Trace	Tan
No. 2 Engine	3	Trace	Grey
Comb. Trans.	3	**Severe**	Grey
No. 1 Engine Trans.	3	Trace	Grey
No. 2 Engine Trans.	3	Trace	Grey
Fwd. Trans.	5	Slight	Grey
Aft Trans	3	Trace	Grey

Aircraft: **A15-202**			
Sample date: **23 September 2002**			
Component	*NAVAIR Rating*	*Visible Contamination*	*Colour*
No. 1 Engine	5	Trace	Tan
No. 2 Engine	**6 (Unacceptable)**	Trace	Tan
Comb. Trans.	3	**Severe**	Grey
No. 1 Engine Trans.	3	Moderate	Grey
No. 2 Engine Trans.	3	**Severe**	Grey
Fwd. Trans.	3	Moderate	Grey
Aft Trans	3	Trace	Grey

A.1. Visible Contamination Scale Used for Filter Patch Examination



Appendix B: Oil Chemical and Physical Property Data

B.1. A15-102

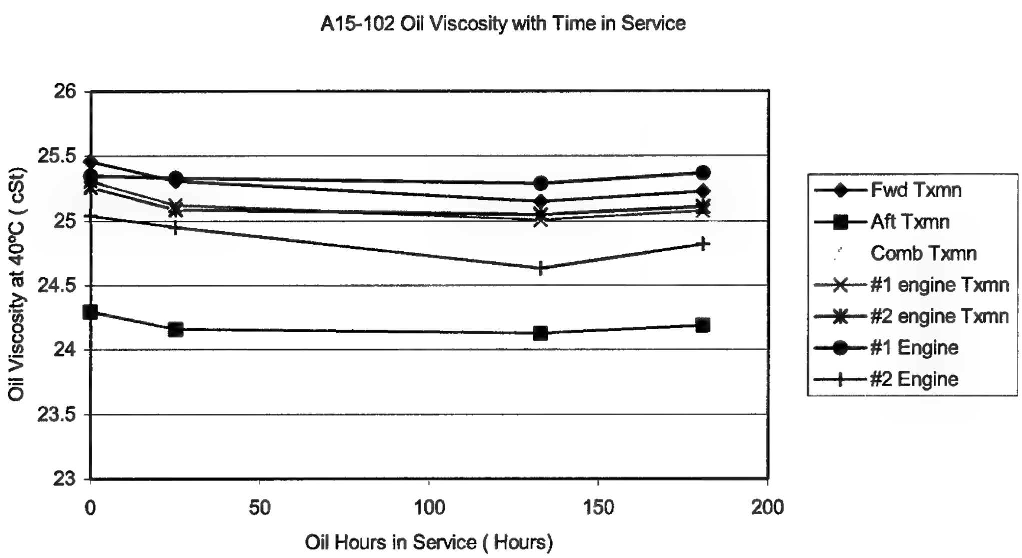


Figure B1.1 A15-102 Viscosity trend data

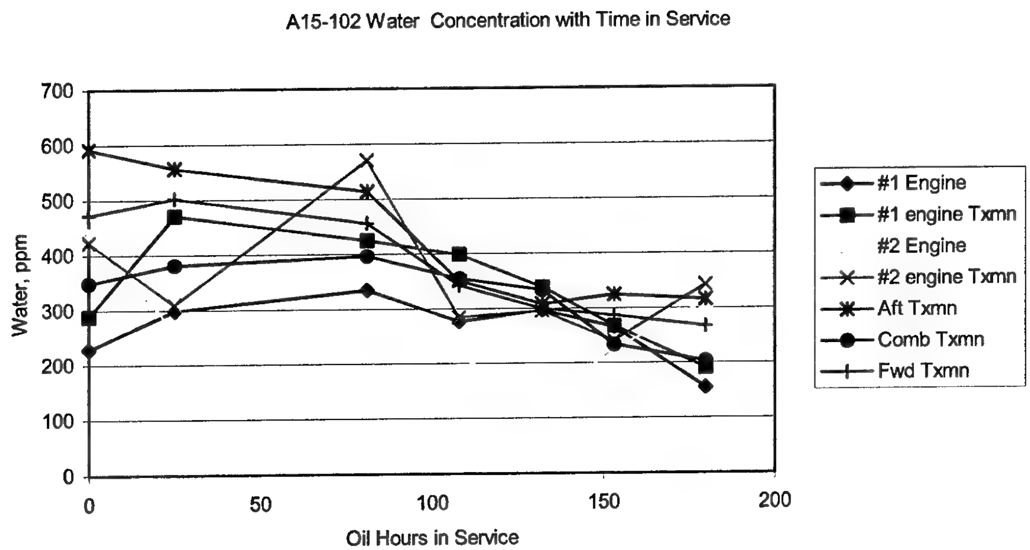


Figure B1.2 A15-102 Water trend data

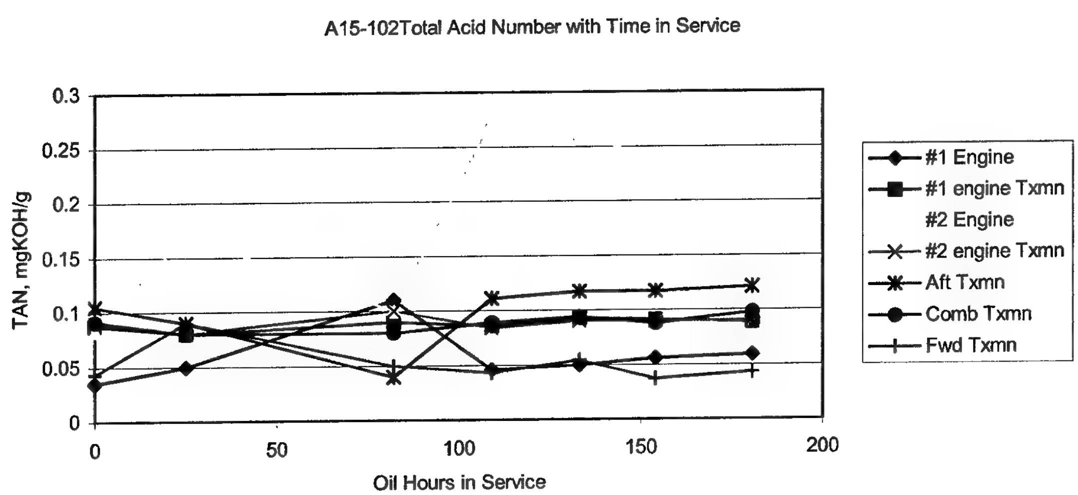


Figure B1.3 A15-102 TAN trend data

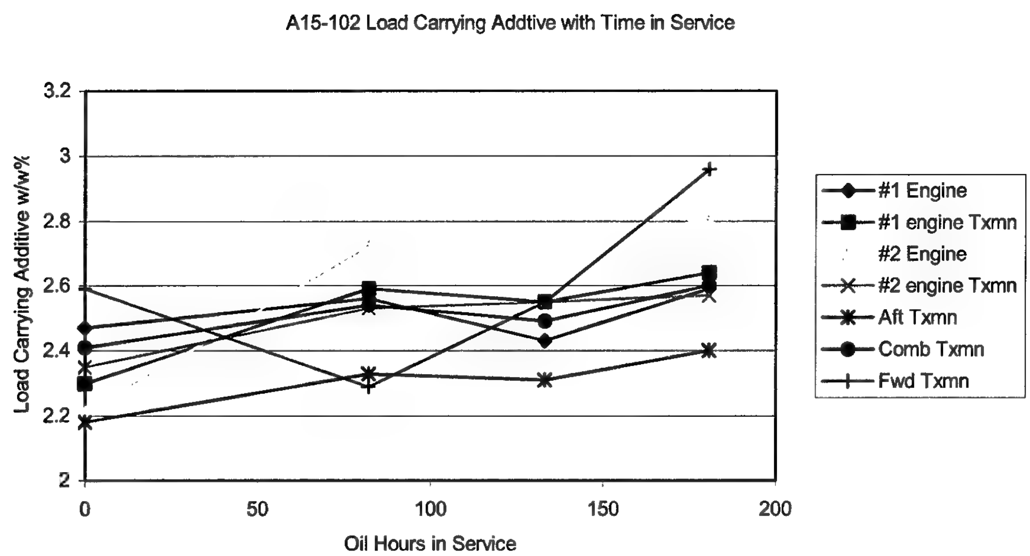


Figure B1.4 A15-102 Load Carrying Additive Trend Data

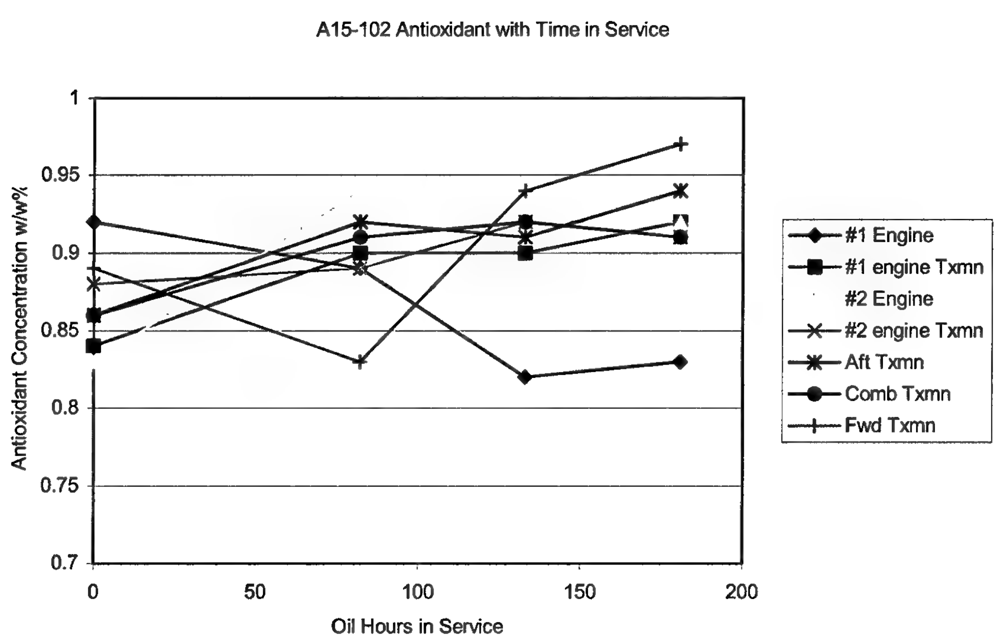


Figure B1.5 A15-102 Antioxidant Concentration Trend Data

Table B1 A15-102 oil condition data

Component (A15-102)	Component Hours (Life)	Top Ups (Quarts)	Load Carrying Additive, w/w %	Antioxidant, w/w %	TAN, mgKOH/g
#1 Engine	1735.1	2.25	2.47	0.72	0.035
#1 Engine	1816.3	2	2.56	0.89	0.11
#1 Engine	1843.2	0			0.046
#1 Engine	1867.3	1	2.43	0.82	0.05
#1 Engine	1888.3	1			0.056
#1 Engine	1914.9	1	2.59	0.83	0.059
#1 Engine					0.05
#1 engine Txmn	121.9	0	2.3	0.84	0.088
#1 engine Txmn	223.7	0	2.59	0.9	0.09
#1 engine Txmn	250.6	0			0.086
#1 engine Txmn	274.7	0	2.55	0.9	0.093
#1 engine Txmn	295.7	0			0.091
#1 engine Txmn	322.3	0	2.64	0.92	0.089
#1 engine Txmn					0.08
#2 Engine	2120.9	1	2.72	0.94	0.1
#2 Engine	2181.2	1			0.274
#2 Engine	2205.3	0.75	2.77	0.92	0.262
#2 Engine	2226.3	1.5			0.237
#2 Engine	2252.9	1	2.8	0.92	0.23
#2 Engine	2739.2	2	2.21	0.83	0.083
#2 Engine					0.17
#2 engine Txmn	23.7	0	2.53	0.89	0.1
#2 engine Txmn	906.7	0	2.35	0.88	0.09
#2 engine Txmn	1370	0			0.084
#2 engine Txmn	1394.1	0	2.55	0.92	0.09
#2 engine Txmn	1415.1	0			0.09
#2 engine Txmn	1441.7	0	2.57	0.91	0.09
#2 engine Txmn					0.08
Aft Txmn	1270.1	0	2.18	0.86	0.105
Aft Txmn	1352.3	1	2.33	0.92	0.04
Aft Txmn	1379.2	2			0.111
Aft Txmn	1403.3	0	2.31	0.91	0.117
Aft Txmn	1424.3	2			0.117
Aft Txmn	1450.9	0	2.4	0.94	0.121
Aft Txmn					0.09
Comb Txmn	1321.2	6	2.41	0.83	0.091
Comb Txmn	1403.4	0	2.54	0.91	0.08
Comb Txmn	1430.3	1			0.089
Comb Txmn	1454.4	0	2.49	0.92	0.094
Comb Txmn	1475.4	3			0.088
Comb Txmn	1502	1	2.6	0.91	0.098
Comb Txmn					0.08
Fwd Txmn	1270.1	0	2.59	0.89	0.043

Fwd Txmn	1352.3	2	2.29	0.83	0.05
Fwd Txmn	1379.2	0			0.043
Fwd Txmn	1403.3	0	2.55	0.94	0.054
Fwd Txmn	1424.3	3			0.037
Fwd Txmn	1450.9	2	2.96	0.97	0.043
Fwd Txmn					0.09

B.2. A15-202

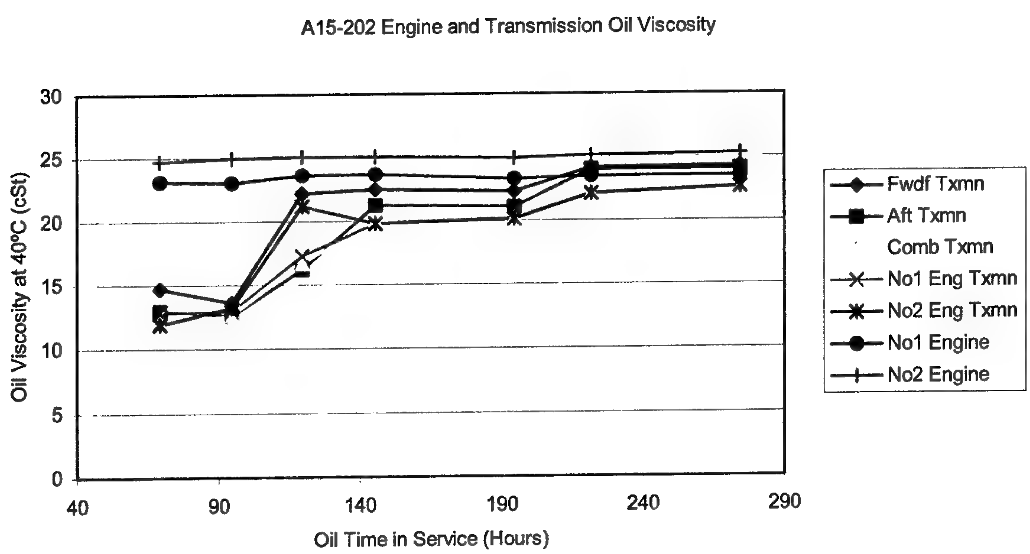


Figure B2.1 A15-202 Viscosity Trend Data

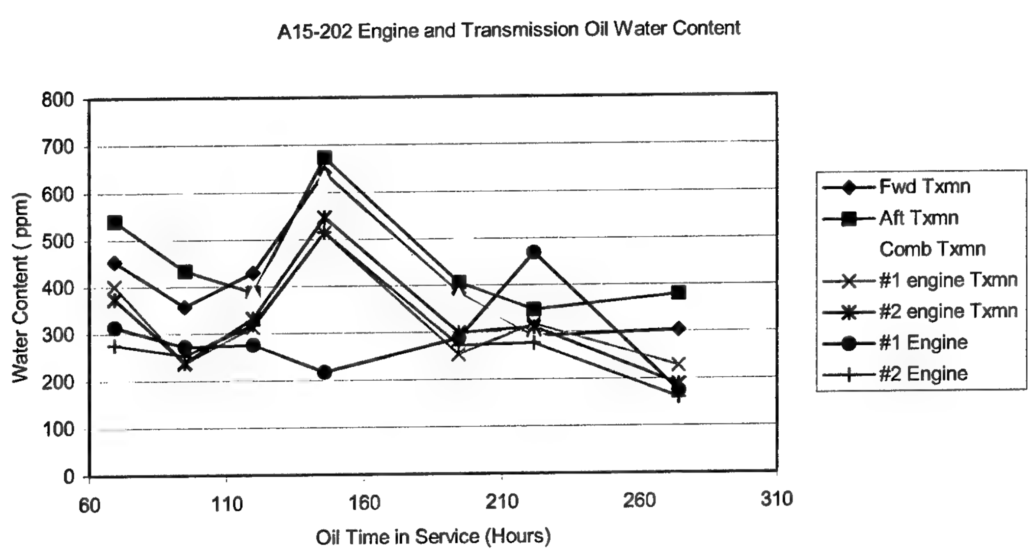


Figure B2.2 A15-202 Water Trend Data

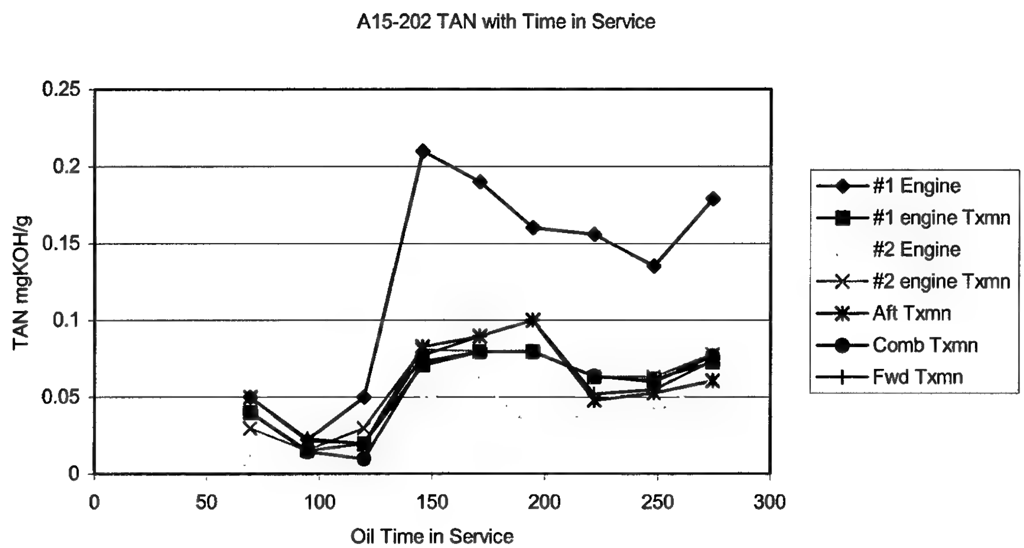


Figure B2.3 A15-202 TAN Trend Data

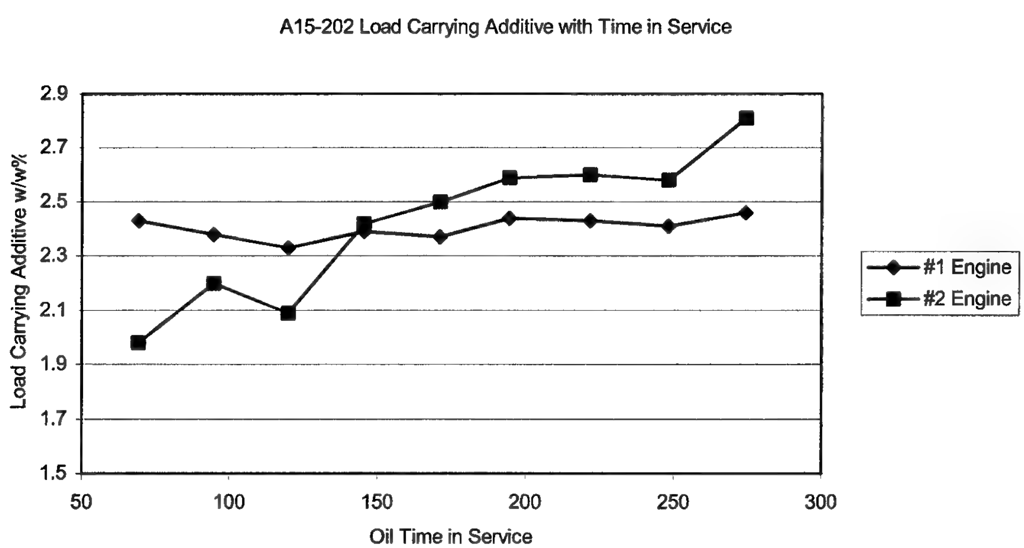


Figure B2.4 A15-202 Load Carry Additive Trend Data

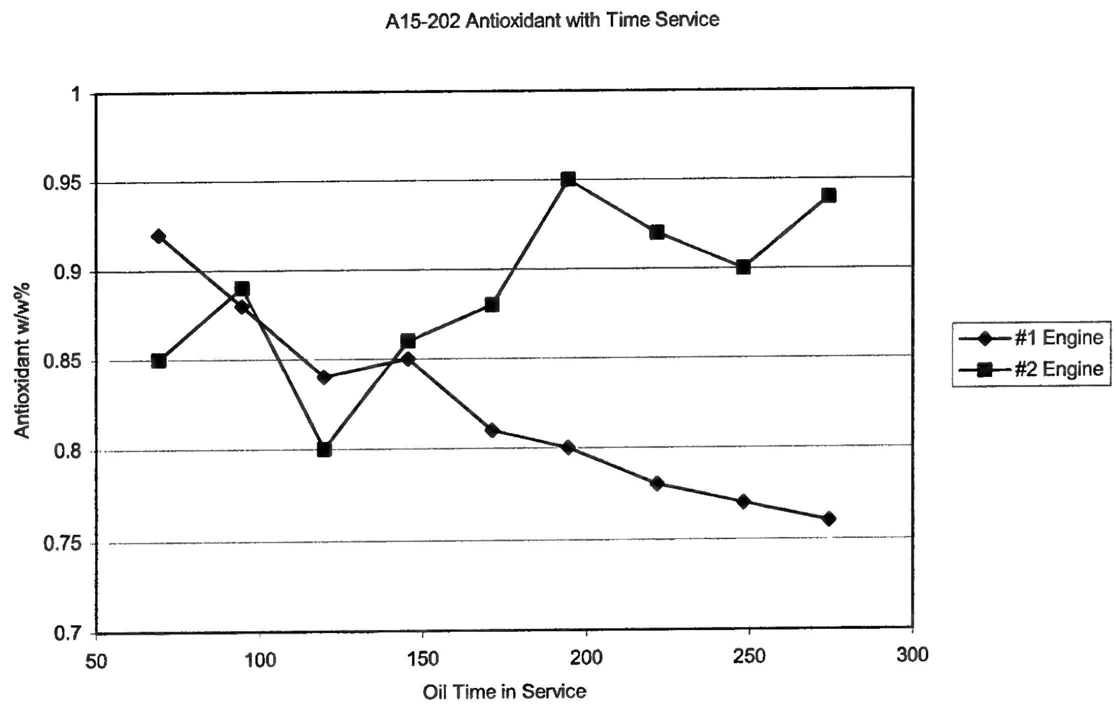


Figure B2.5 A15-202 Antioxidant Trend Data

Table B2 A-15-202 Oil condition data.

Component (A15-202)	Oil hours in service	Top Ups (Quarts)	Load Carrying Additive, w/w %	Antioxidant (TCP), w/w %	TAN, mgKOH/g
#1 Engine	69.3	0	2.43	0.92	0.05
#1 Engine	94.7	0	2.38	0.88	0.02
#1 Engine	119.9	1	2.33	0.84	0.05
#1 Engine	145.6	1	2.39	0.85	0.21
#1 Engine	171.2	1	2.37	0.81	0.19
#1 Engine	194.5	0	2.44	0.8	0.16
#1 Engine	221.7	0.5	2.43	0.78	0.156
#1 Engine	248.1	0	2.41	0.77	0.135
#1 Engine	274.4	0.75	2.46	0.76	0.179
#1 Engine			2.41	0.81	0.175
#1 engine Txmn	69.3	0			0.04
#1 engine Txmn	94.7	0			0.015
#1 engine Txmn	119.9	0			0.02
#1 engine Txmn	145.6	0			0.071
#1 engine Txmn	171.2	0			0.08
#1 engine Txmn	194.5	0			0.08
#1 engine Txmn	221.7	0			0.063
#1 engine Txmn	248.1	0			0.062
#1 engine Txmn	274.4	0			0.073
#1 engine Txmn					0.066
#2 Engine	69.3	0	1.98	0.85	0.01
#2 Engine	94.7	0	2.2	0.89	0.01
#2 Engine	119.9	1	2.09	0.8	0.01
#2 Engine	145.6	0	2.42	0.86	0.048
#2 Engine	171.2	1	2.5	0.88	0.06
#2 Engine	194.5	11	2.59	0.95	0.03
#2 Engine	221.7	0.5	2.6	0.92	0.04
#2 Engine	248.1	1	2.58	0.9	0.039
#2 Engine	274.4	0	2.81	0.94	0.062
#2 Engine			2.5	0.93	0.04
#2 engine Txmn	69.3	0			0.03
#2 engine Txmn	94.7	0			0.02
#2 engine Txmn	119.9	0			0.03
#2 engine Txmn	145.6	0			0.081
#2 engine Txmn	171.2	0			0.08
#2 engine Txmn	194.5	0			0.08
#2 engine Txmn	221.7	0			0.063
#2 engine Txmn	248.1	0			0.063
#2 engine Txmn	274.4	0			0.078
#2 engine Txmn					0.068
Aft Txmn	69.3	0			0.05
Aft Txmn	94.7	0			0.02
Aft Txmn	119.9	0			0.02

Aft Txmn	145.6	0			0.083
Aft Txmn	171.2	0			0.09
Aft Txmn	194.5	2			0.1
Aft Txmn	221.7	2.5			0.048
Aft Txmn	248.1	1.5			0.053
Aft Txmn	274.4	0.5			0.061
Aft Txmn					0.049
Comb Txmn	69.3	0			0.04
Comb Txmn	94.7	0			0.01
Comb Txmn	119.9	0			0.01
Comb Txmn	145.6	22			0.073
Comb Txmn	171.2	4			0.08
Comb Txmn	194.5	0			0.08
Comb Txmn	221.7	20			0.064
Comb Txmn	248.1	1			0.06
Comb Txmn	274.4	2			0.077
Comb Txmn					0.067
Fwd Txmn	69.3	0			0.05
Fwd Txmn	94.7	0			0.02
Fwd Txmn	119.9	1.5			0.02
Fwd Txmn	145.6	0			0.077
Fwd Txmn	171.2	0			0.09
Fwd Txmn	194.5	1			0.1
Fwd Txmn	221.7	0			0.052
Fwd Txmn	248.1	0			0.055
Fwd Txmn	274.4	0.75			0.074
Fwd Txmn					0.051

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Andrew Becker and Paul Rawson

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19. ABSTRACT

This report describes the findings of an investigation into the health of the lubricating oil in two Australian Army CH-47D helicopters. One of the aims of this investigation was to assess the applicability of an existing filter patch test kit for lubricating oil in order to provide basic contamination and wear debris information. The information provided by the filter patch test kit would be of particular benefit when aircraft are deployed to remote localities. The filter patch test kit used for this investigation is currently used by the Australian Defence Force to assess hydraulic fluid health. Another aim of this investigation was to assess a number of chemical and physical properties of the oil in order to obtain a better understanding of the oil condition in operational CH-47D helicopters. This investigation also investigated whether certain aspects of the oil's chemical condition could be used to assess the health of the aircraft engines and transmissions.